



Combined CDF Search for Single Top Quark s -channel Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV with the Full Dataset

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We combine results from CDF on searches for single top s -channel production in the full data set of proton-antiproton collisions at $\sqrt{s} = 1.96$ TeV recorded by the CDF II detector at the Tevatron, corresponding to an integrated luminosity of 9.45 fb^{-1} . Assuming a top quark mass of $172.5 \text{ GeV}/c^2$, we measure a cross section of $\sigma_{s\text{-}ch}^{\text{meas}} = 1.38_{-0.37}^{+0.38}$ (stat+syst) pb. There is an excess of data events with respect to the background estimation. The p -value for a background fluctuation to produce this excess is 0.000016, corresponding to a significance of 4.2 standard deviations.

I. INTRODUCTION

The top quark was discovered in 1995 at the Fermilab Tevatron proton-antiproton collider [1] [2] in top-antitop pair production via the strong interaction. Alternative production modes proceed via the weak interaction involving a W - t - b vertex, leading to a single top-quark in the final state. Top quarks are produced singly in the Standard Model (SM) through three different mechanisms, resulting in different final states: the t -channel exchange of a W boson at the LO and NLO, and the s -channel W boson exchange, and the associated production of an on-shell W boson and a top-quark (Wt mode), that has a negligible cross section at the Tevatron. The single top-quark production has been observed at the Tevatron [3] [4] [5] based on a combination of t -channel and s -channel processes in 2009, and the t -channel single top-quark production has also been established by the LHC experiments [6] [7]. However the s -channel production mode has not been observed yet by itself. Recently DØ reported the first evidence of the single top s -channel production [10]. The search for this process is particularly interesting since it may provide evidence for new physics, like the existence of W 's or of charged Higgs bosons [8]. Techniques developed to search for s -channel single top production could be used for a search of $t\bar{b}$ resonances [9].

We combine the two CDF s -channel optimized analyses. Both the analyses use the total 9.45fb^{-1} integrated luminosity available at CDF to look for the presence of single top-quarks from s -channel production, exploiting a new b -jet identification algorithm optimized for $H \rightarrow b\bar{b}$ searches.

In the $\nu b\bar{b}$ analysis, events consistent with a W -boson decay plus two energetic b -quark jets are selected. A single, isolated lepton with $p_T = 20 \text{ GeV}/c$ is required, together with the presence of missing transverse energy (\cancel{E}_T) with a different threshold depending on the quality of the lepton reconstruction algorithm in use. The sample is subdivided according to the lepton category and the number of b -tagged jets. The measured single top s -channel cross section in the $\nu b\bar{b}$ sample is $\sigma_{s\text{-}ch}^{\text{meas}} = 1.41_{-0.42}^{+0.44}$ (stat+syst) pb with a significance of 3.8 standard deviation.

In the $\cancel{E}_T b\bar{b}$ analysis, events are selected that contain no reconstructed leptons, large missing transverse energy in the calorimeter \cancel{E}_T and two or three hadronic jets with high transverse momentum, at least one of which is required to originate from a b -quark. The measured single top s -channel cross section in the $\cancel{E}_T b\bar{b}$ sample is $\sigma_{s\text{-}ch}^{\text{meas}} = 1.07_{-0.57}^{+0.64}$ (stat+syst) pb with a significance of 1.9 standard deviation.

II. SIGNAL AND BACKGROUND MODEL

Shape of distributions in top-quark events via pair and electroweak production, in V +jets events, in WH/ZH and in diboson events (VV) are modeled by simulation. The ALPGEN generator [16] is used to estimate V +jets and the associated production of Higgs bosons with a W or a Z , POWHEG [17] for electroweak t -channel production of top quarks as well as for the s -channel signal, and PYTHIA [18] for top quark pair production and VV events. The parton showering is performed by PYTHIA. The event generation process includes a simulation of the detector response [20], and the resulting samples are subjected to the same reconstruction and analysis chain as the data. The normalization of electroweak t -channel production, VV events and top quark pair production is constrained to the theoretical cross section value for both the $\nu b\bar{b}$ and the $\cancel{E}_T b\bar{b}$ analyses. In particular, for the normalization of $t\bar{t}$ the last Mitov calculation ($7.24_{-0.27}^{+0.23}$ pb [19]) is used.

For the $\nu b\bar{b}$ analysis, also the normalization of Z +jets is normalized to the theoretical prediction, while the W +jets normalization is data-derived.

For the $\cancel{E}_T b\bar{b}$ analysis, an *in situ* calibration of W/Z +jets background is performed directly in the final fit.

QCD multijet is data-derived in both the analyses and validated in several control regions: for the $\nu b\bar{b}$ analysis, data with no isolated leptons are used as QCD model, while in the $\cancel{E}_T b\bar{b}$ analysis a tag rate matrix method is applied.

III. SYSTEMATICS

Since the same source may affect the uncertainty of several background and signal distributions, systematic uncertainties are grouped according their sources. The systematic uncertainties originating from the same source are considered 100% correlated. The uncertainties from the simulations statistics and those on the normalizations of $t\bar{t}$ (3.5%), single top t -channel (15%), diboson (6%), WH/ZH (5%) are correlated between all the different categories considered by the $\nu b\bar{b}$ and $\cancel{E}_T b\bar{b}$ analyses. The correlated uncertainties include also luminosity measurement (6%), b -tagging efficiency (8 to 16%) and mistag rate (4 to 37%). All the other uncertainties showed in [23] and [24] are taken as uncorrelated.

IV. CROSS SECTION EXTRACTION

We perform a binned likelihood fit to probe for a single top s -channel signal in the presence of SM backgrounds. The likelihood is the product of Poisson probabilities over the bins of the final discriminant distribution. The mean number of expected events in each bin includes contributions from each background source and from the single top s -channel processes (assuming a top quark mass of $172.5 \text{ GeV}/c^2$). We employ a Bayesian likelihood method [26] with a flat, non-negative, prior probability for the single top s -channel production cross section times branching fraction and truncated Gaussian priors for the uncertainties on the acceptance and shape of the backgrounds. We combine the all the regions considered in the $l\nu b\bar{b}$ and $\cancel{E}_T b\bar{b}$ analyses by taking the product of their likelihoods and simultaneously varying the correlated uncertainties.

We check our cross section fit method using 10000 pseudoexperiments generated varying the input signal cross section and systematic uncertainties, which are then fit to measure the signal cross section. The procedure used cannot produce a negative cross section measurement, since the priors are zero for negative values. For an input cross section of zero, half of the measured cross sections then are exactly zero, and the other half form a distribution of positive fit cross sections. We therefore use the median fit cross section to avoid the bias which would be introduced by using the average instead. The expected cross section turned to be:

$$\sigma_{s-ch}^{\text{exp}} = 1.00^{+0.33}_{-0.33} \times \sigma_{s-ch}^{\text{SM}}$$

We conclude that the adopted fit technique does not introduce any significant bias .

V. RESULTS

By scanning the final discriminants of the two analyses and using the statistical test described above, we measure a single top quark s -channel production cross section of

$$\sigma_{s-ch}^{\text{meas}} = 1.38^{+0.38}_{-0.37} \text{ pb}$$

This result is consistent with the standard model cross section $\sigma_{s-ch}^{\text{SM}} = 1.05 \pm 0.05 \text{ pb}$. In Fig. 1 the posterior probability density is shown.

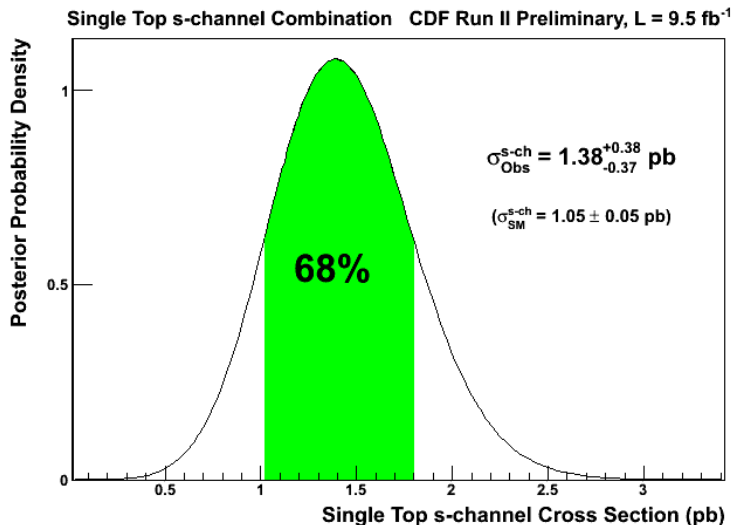


FIG. 1. Posterior probability density distribution

VI. P-VALUE

We also measured the p -value by generating pseudo-experiment with both background only and signal plus background hypothesis, as shown in Fig. 2. The p -value for the observed cross section is 0.000016, which corresponds to a significance of 4.2σ (expected 3.4σ).

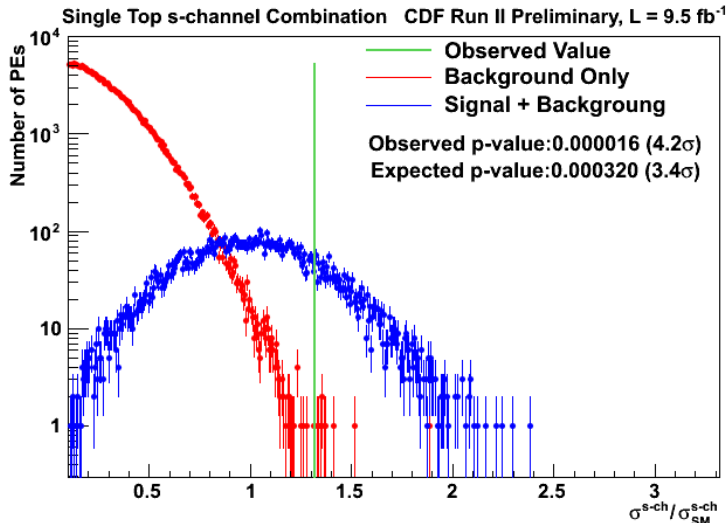


FIG. 2. Pseudo-experiment output with background only hypothesis and background plus signal hypothesis.

VII. SUMMARY

We combined the CDF searches for single top quark s -channel production using the full CDF II data sample, corresponding to 9.45fb^{-1} of integrated luminosity accumulated during Run II of the Tevatron. We measure a cross section of

$$\sigma_{s-ch}^{\text{meas}} = 1.38_{-0.37}^{+0.38} \text{ pb}.$$

The measurement is compatible with standard model prediction and is also compatible with previous CDF measurement. The observed p -value corresponds to a significance of 4.2σ , establishing a stronger evidence of the single top s -channel production.

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